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(54) **Graphite heat exchange assembly with silicon carbide tube inserts and fluoropolymer coating**

(57) A graphite heat exchange assembly for efficient heat transfer between a process fluid and a service fluid. The heat exchange assembly includes a thermally conductive graphite body (112) having an external surface and a plurality of bores (172) receiving the process fluid. A plurality of passageways (174) receive the service fluid. The bores and the passageways facilitate efficient heat transfer between the process fluid and the service fluid. A multiplicity of silicon carbide tubes (180), having exposed ends and an internal diameter, are disposed in the bores, the passageways, or both. A fluoropolymer coating (190) is applied to the external surface of the graphite body and to the ends of the silicon carbide tubes. The internal diameter of the silicon carbide tubes is maintained free of the coating.

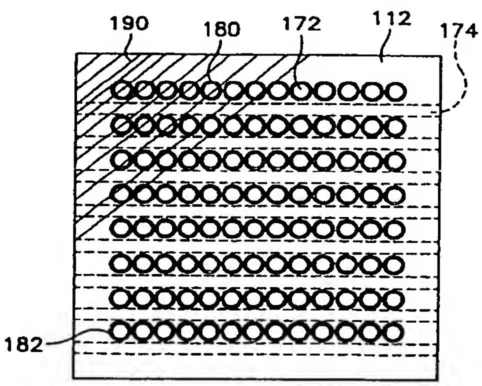

FIG. 4A

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Description

Field of the Invention

The present invention relates generally to heat exchangers and, more specifically, to a heat exchange assembly which contains a plurality of bores having silicon carbide tube inserts and which has a fluoropolymer coating deposited on certain external surfaces of the heat exchange assembly and on the ends of the silicon carbide inserts.

Background of the Invention

There has been wide industrial use of heat exchange assemblies in which two or more fluids at differing temperatures exchange heat to raise the temperature of one fluid and to lower the temperature of the other. Heat exchange assemblies are generally constructed of a container or shell and a core member positioned within the shell. In operation, a first fluid is introduced into the shell, passes through or around the core member, and exits out another portion of the shell. A second fluid is also introduced into the shell and passes through a multiplicity of holes or passageways in the core member which are closely adjacent those bores through which the first fluid is passing. Thus, there is an efficient exchange of heat between the two fluids. In commercial operations, the fluid which is to be heated or cooled is called the process fluid and the fluid which provides the heat or absorbs heat is called the service fluid. These fluids may be gases or liquids or, as in the case of steam that condenses within the core, a mixture of both.

Thus, heat exchange assemblies are well-known devices; they have many different applications. For example, the chemical and pharmaceutical industries use heat exchange assemblies in chemical and pharmaceutical processing. Typically, a process fluid such as a battery acid (H_2SO_4) in the chemical industry or an acetone in the pharmaceutical industry is processed at high temperatures. A heat exchange assembly may be used to remove heat from the process fluid in a specific processing step.

In the field of heat exchange assemblies, and in many other technological fields, there are ever-increasing needs for refractory structures and surfaces which are stable and which retain strength at much higher operating temperatures than previously used. Heat exchange assemblies often operate in the presence of oxidizing or reducing atmospheres, high pressures or vacuums, and other severe and unusual environments which ordinary materials of construction will not withstand. Graphite is a material which admirably satisfies many of the necessary requirements in this field. Therefore, heat exchange assemblies are often constructed of graphite components and many are formed around a single-piece graphite block or gasket assemblies of such blocks.

Graphite has highly desirable properties including low density, high melting or sublimation point, and high structural strength at higher temperatures. These characteristics permit graphite to be used where most other structural materials, including common metals, are unsatisfactory. The normal properties of graphite are inadequate, however, in certain respects and in particular environments. Graphite erodes and corrodes at high fluid pressures, velocities, and temperatures. Many fluids and other materials react with graphite or are absorbed in an undesirable manner in certain environments.

The present practice is to apply a resin to the graphite used to construct the heat exchange assembly. The resin impregnates the graphite, penetrating into the porosity of the graphite block and closing off microporosity. Thus, the resin renders the graphite block impermeable to process fluids. The known resins (e.g., phenolics) used for such purposes are not chemically resistant to many process fluids of interest, however, and have severe operating temperature limitations. Although heat exchange assemblies incorporating resin-impregnated graphite components achieve, for example, good hydrostatic test results, the components often do not withstand steam cycle testing due to resin deterioration.

The only recourse at present is to use exotic metals (such as tantalum or titanium) or metal alloys (such as hastelloy) to construct heat exchange assemblies for those applications where resin-impregnated graphite is not technically satisfactory. Heat exchange assemblies constructed of uncommon metals or metal alloys are very expensive: on the order of five times the cost of heat exchange assemblies which incorporate resin-impregnated graphite components. Therefore, a lower cost alternative for those heat exchange applications in which resin-impregnated graphite is impractical would be a commercially desirable product.

The search for such a product encounters many attempts. Silicon carbide has long been recognized as an extremely valuable refractory material. See, for example, United States Patent Number 2,784,112 issued to Nicholson in 1957. Silicon carbide is one of the hardest engineering materials, resists abrasion, and is unreactive to most chemicals. These advantageous properties have prompted the use of silicon carbide for gas turbine and nuclear reactor components and for pipes, reaction vessels, pumps, stirrers, valves and other chemical apparatus components.

United States Patent Number 5,323,849 issued to Korczynski et al. discloses a corrosion resistant shell-and-tube heat exchange assembly for use with corrosive fluids. The heat exchange assembly uses corrosion and erosion resistant tube sheets, tubes, and a shell. The reference discloses that the corrosion resistant material of the tubes may comprise, among other materials, a sintered alpha silicon carbide ceramic. The tubes are secured in apertures in the tube sheets by an epoxy adhesive.

United States Patent Number 4,360,057 issued to Koump discloses a high-temperature, abrasion-resistant heat exchange assembly which includes a plurality of tube sheets dividing the interior of the shell into separate consecutive chambers. The tubes are made from a ceramic material, preferably dense silicon carbide. United States Patent Number 5,238,057 issued to Schelter et al. discloses a finned-tube heat exchange assembly in which the tubes are silicon-infiltrated silicon carbide.

United States Patent Number 5,036,903 issued to Shook also discloses the use of tubes comprising corrosion resistant materials such as silicon carbide. More particularly, however, Shook teaches a graphite tube condensing heat exchange assembly for recovering heat from a corrosive gas stream. The reference discloses the use of polytetrafluoroethylene (PTFE) coatings to provide corrosion-resistance and recognizes that such fluoroplastics tend to be somewhat insulative if used in thicker layers on the inside surfaces of metal tubes used in prior art heat exchange assemblies. Also disclosed is the use of a corrosion-protective coating system for side-aperatured tube sheets through which resin-impregnated graphite tubes penetrate. The coating system comprises an inner silicon-carbide impregnated coating affixed to the tube sheet and a fluoroplastic layer over the silicon carbide impregnated layer. This bi-layered system provides improved corrosion-protection and erosion-resistance in protecting steel tube sheets.

Shook teaches impregnated graphite and silicon carbide as alternative materials for the tubes of his shell-and-tube type heat exchange assembly. The two materials are not used in combination. In addition, the corrosion-protective coating system is placed on the inside surface of the metal tube sheets--neither on an external surface of the heat exchange assembly nor on the tubes themselves.

Silicon carbide coated graphite has also been used to construct heat exchange assemblies. United States Patent Number 3,250,322 issued to McCrary, Jr. discloses a corrosive fluid heat exchange assembly comprising a graphite body having walls which are coated with beta silicon carbide in order to render the heat exchange assembly fluid-impervious. Referring to Figure 1, the assembly is constructed with a metal cylindrical shell 12 with end plates 14 and 16. A plurality of graphite elements 24, 26, 28, 30, 32, and 34 are stacked within shell 12.

The corrosive liquid is confined to the interior of the header elements 24 and 34 and the heat exchange elements 26, 28, 30, and 32. Radial bores 64 and axial bores 70 run through the heat exchange elements. The bores 64 and 70, the surfaces of the header elements 24 and 34, and the surfaces of the heat exchange elements 26, 28, 30, and 32--all are uniformly coated with fluid-impervious, beta silicon carbide which protects the base material of the elements from oxidation and corrosion. The silicon carbide is also extremely hard and protects the elements from abrasive wear. Although they may be tungsten or molybdenum, the header and heat exchange elements are preferably fabricated from graphite.

Finally, a number of prior art patents disclose the use of protective, corrosion-resistant coatings. United States Patent Number 5,199,486 issued to Balmer et al. describes a coated heat exchange assembly wherein tetrafluoroethylene is used to prevent the build-up of minerals. The heat exchange array 30 is shown in Figure 2 and includes a plurality of steam or fluid tubes 31A-31N coated with a non-stick material such as Teflon® (a trademark of E.I. du Pont de Nemours Company for a tetrafluoroethylene polymer). A plurality of steam or fluid tubes 32A-32N are also coated with Teflon®-like material and are placed beneath 31A-31N in order to provide an exchange of heat between two flowing liquids. United States Patent Number 4,669,530 issued to Warner is directed to a heat exchange assembly which is used to cool sulfur trioxide wherein the heat exchange assembly must be protected against corrosion. Various fluoroplastics are used as thin coverings on the heat exchange tubes in order to prevent corrosion while allowing good heat transfer.

There is the problem of applying the coating in such a manner that an adhesive bond between the graphite and the coating will be obtained. Chemical vapor deposition (CVD) is a known process for forming a coating directly on a graphite body; this is the process disclosed by McCrary, Jr. in the '322 patent. The process involves passing, in vapor form, a halide of the metal to be deposited over the graphite body at such a temperature that the halide is thermally decomposed and the metal is deposited on the surface of the graphite.

It is difficult to obtain uniform coatings over extended surfaces using this method. In some cases, special arrangements such as split gas flows, baffling, moving jets, moving substrates, or moving temperature gradients are used to obtain uniform coatings. Some substrates, especially those with complex shapes, are virtually impossible to coat by any of the standard techniques. Thus, although the coating processes used for relatively simple parts such as single tubes or rods are well known, heat exchange assemblies have a large, relatively complex geometry (including a plurality of angled through-holes) which renders the known coating processes ineffective.

To overcome the shortcomings of the prior art, an improved graphite heat exchange assembly which incorporates silicon carbide tubes and a fluoropolymer coating on the tube ends and graphite surfaces is provided. One object of the invention is to provide a heat exchange assembly for handling fluids which would normally corrode graphite and most metals. A related object is to provide a heat exchange assembly which can handle oxidizing and other corrosive process fluids without deleterious effects on the assembly. Another object is to protect the graphite heat exchange assem-

bly from chemical attack by many chemical media of interest to the process industry.

A more general object is to provide a heat exchange assembly having good thermal conductivity which may be used over a wide temperature range. Yet another object of this invention is to coat a graphite heat exchange assembly with a uniform, adherent coating of fluoropolymer. It is still another object of the present invention to provide a heat exchange assembly with a hard, durable surface free of microporosity and able to resist corrosion and abrasion. A related object is to seal off the surface porosity of the pre-machined graphite heat exchange assembly.

An additional object is to provide a heat exchange assembly that resists fouling and the formation of scale deposits. Still another object is to prevent the graphite of the heat exchange assembly from dissolving or flaking and, thereby, to prevent contamination of the process fluid. Another object of the present invention is to provide components which can be used to retrofit existing heat transfer assemblies.

Summary of the Invention

To achieve these and other objects, and in view of its purposes, the present invention provides a graphite heat exchange assembly for efficient heat transfer between a process fluid and a service fluid. The heat exchange assembly includes a thermally conductive graphite body having an external surface and a plurality of bores receiving the process fluid. A plurality of passageways receive the service fluid. The bores and the passageways facilitate efficient heat transfer between the process fluid and the service fluid. A multiplicity of silicon carbide tubes, having exposed ends and an internal diameter, are disposed in the bores, the passageways, or both. A fluoropolymer coating is applied to the external surface of the graphite body and to the ends of the silicon carbide tubes. The internal diameter of the silicon carbide tubes is maintained free of the coating.

It is to be understood that both the foregoing general description and the following detailed description are exemplary, but are not restrictive, of the invention.

Brief Description of the Drawing

The invention is best understood from the following detailed description when read in connection with the accompanying drawing, in which:

FIG. 1A is a top view of a conventional, cylindrical block heat exchange assembly;

FIG. 1B is a bottom view of the heat exchange assembly shown in FIG. 1;

FIG. 1C is a side view, in partial cross-section, of the heat exchange assembly shown in FIGS. 1A and 1B;

FIG. 1D is a side view, in partial cross-section and partial cut-away, of the heat exchange assembly shown in FIGS. 1A, 1B, and 1C;

FIG. 1E is an enlarged sectional view taken along the line 1E-1E of FIG. 1C;

FIG. 2A is a fragmentary, sectional view of an intermediate block of the cylindrical block type heat exchange assembly in accordance with the present invention;

FIG. 2B is an enlarged, detailed view taken of the circle labeled 2B in FIG. 2A;

FIG. 3A is a perspective view of a disassembled, conventional, cubic block heat exchange assembly;

FIG. 3B is a cross-sectional view of the heat exchange assembly shown in FIG. 3A having a typical three-pass flow pattern;

FIG. 3C is a cross-sectional view of the heat exchange assembly shown in FIG. 3A having a typical four-pass flow pattern;

FIG. 4A is a fragmentary, sectional view of the process side of the cubic type heat exchange assembly in accordance with the present invention;

FIG. 4B is a fragmentary, sectional view of the service side of the cubic type heat exchange assembly in accordance with the present invention;

FIG. 5 is a cross-sectional view of a conventional, shell-and-tube heat exchange assembly; and

FIG. 6 is a cross-sectional view of the shell-and-tube heat exchange assembly in accordance with the present invention.

Detailed Description of the Invention

Graphite heat exchange assemblies have a number of advantages which make them especially desirable for high temperature, high chemical corrosion usage. For example, graphite withstands thermal shock to a limited extent and resists chemical corrosion, with the exception of certain strong oxidizing chemicals. Moreover, graphite structures have excellent stability at elevated temperatures, as well as good thermal conductivity.

There are certain disadvantages to graphite structures which limit their use in heat exchange assemblies. For example, graphite has relatively low tensile strength so that tubes made of graphite are relatively fragile.

Graphite is also porous and permeable to various fluids. This permeability may be overcome by impregnating the graphite with certain synthetic resins, but this reduces the stability of the graphite-synthetic resin compositions at high temperatures.

Briefly, the subject invention comprises a conventional graphite heat exchange assembly and incorporates two features which, in combination, protect the heat exchange assembly against corrosion. First, tubes made of alpha silicon carbide are inserted into bores drilled in the graphite to carry the process fluid, into passageways drilled in the graphite to carry the service fluid, or both. Second, a fluoropolymer coating is deposited on certain external surfaces of the graphite heat exchange assembly and on the ends of the silicon carbide tubes. Neither feature alone will assure the increased corrosion protection and enhanced performance characteristics provided by the two features in combination.

Turning first to the silicon carbide tubes, silicon carbide, by nature of its chemical properties and impervious nature, protects the base graphite material of the heat transfer assembly from oxidation and corrosion. The silicon carbide is also extremely hard and protects the heat transfer assembly from abrasive wear caused by solids entrained in the process fluid.

The thermal properties of graphite and silicon carbide combine to give the heat transfer assembly good thermal conductivity. The stability of silicon carbide at high temperatures and the substantially matching coefficients of thermal expansion of the graphite and silicon carbide allow the heat transfer assembly to be used at high temperatures in high thermal gradients where efficiency is maximum. Moreover, the silicon carbide tubes are sufficiently hard that the heat exchange assembly can by used under severe abrasive conditions and still offer a long service life.

Preferably, the tubes of the present invention are made of alpha silicon carbide. Alpha silicon carbide is very dense and virtually impervious to fluids. Alpha silicon carbide tubes may be produced by pressureless sintering an ultra-pure, sub-micron powder. The powder is mixed with non-oxide sintering aids, then formed into the tube shape and consolidated by sintering at temperatures above 3632°F.

The sintering process results in a single-phase, fine-grain silicon carbide tube that is pure, uniform, and virtually devoid of porosity. Whether submerged in corrosive environments, subjected to extreme wear and abrasive conditions, or exposed to temperatures in excess of 2552°F, sintered alpha silicon carbide outperforms other commercially available ceramics or metal alloys--including superalloys.

Alpha silicon carbide tubes have extremely high strength and excellent resistance to creep and stress rupture at temperatures up to 3000°F. Specifically, the flexural strength (4 pt.) of sintered alpha silicon carbide is about 58,600 psi at 1500°C; the fracture toughness is about 420 X 10^3 psi/m$^{1/2}$ at 25°C, and the modulus of elasticity is about 59 X 10^6 psi at room temperature.

Alpha silicon carbide is one of the hardest, high-performance materials available, behind boron carbide (B_4C), cubic crystalline boron nitride (BN), and diamond. It has a hardness (Knoop) of about 2800 kg/mm^2 at room temperature. Alpha silicon carbide weighs less than half as much as most metal alloys (40 percent as much as steel). The densities of sintered tubes are consistently in excess of 98 percent of the theoretical density of alpha silicon carbide: 3.21 g/cm^3. The extreme hardness and density of alpha silicon carbide make it ideal for heat exchange assemblies where components are subject to high abrasion and sliding wear. The specific wear rate and coefficient of friction (both pin on disc) of silicon carbide versus silicon carbide are 1 X 10^{-9} mm^2/kg and 0.2, respectively.

The high density, low porosity, and chemical inertness of alpha silicon carbide tubes permit them to function in environments of hot gases and liquids, in oxidizing and corrosive atmospheres, and in strong acids and bases, even at extremely high temperatures. The high thermal conductivity of alpha silicon carbide, combined with its low thermal expansion, produces excellent thermal-shock resistance. The thermal-shock resistance is far better than tungsten carbide, aluminum oxide, and silicon nitride. These properties allow alpha silicon carbide to replace ductile metals in high-temperature heat-exchange assemblies.

The as-sintered surface finish of alpha silicon carbide tubes is excellent (about 64 microinches). This surface quality, combined with tight dimensional control, yields tubes that require little or no additional machining or finish grinding.

Turning to the second feature of the present invention, a fluoropolymer coating is applied to certain external graphite surfaces of the heat exchange assembly and on the ends of the silicon carbide tubes. The coating is not applied inside the silicon carbide tubes because this would hinder the heat transfer across the silicon carbide tubes and through the graphite block. The fluoropolymer is preferably a fluoroelastomer polymer, such as FEP, which can be applied as a coating. (The assignee of the present invention refers to the fluoropolymer coatings as "Graphilor T".)

A suitable example FEP is Neoflon™ coating powder, available from Daikin Industries, Ltd. The coating powder is a fine powder made of tetrafluoroethylene and hexafluoropropylene copolymer. The coating powder is low in melt viscosity and excellent in melt fluidity; consequently, a coating film free of pinholes can be obtained. This coating is ideal for use as a corrosion resistant lining, has excellent thermal and chemical resistance, and desirable anti-stick, sliding, and electric properties.

The fluoropolymer coating is applied to the "raw" (i.e, un-impregnated) graphite. Especially when a strong and dense grade of graphite is used (such as the assignee's grade 2020 graphite) in the heat exchange

assembly, it may be unnecessary to impregnate the graphite after the fluoropolymer coating is applied. This is the case when tubes exist on both circuits, process and service. There is no area for impregnation where the fluoropolymer coating is applied; the fluoropolymer coating penetrates into and fills substantial all exposed pores and crevices in the graphite substrate.

A continuous, adherent, homogeneous fluoropolymer coating of substantially uniform thickness (about 3.5 ± 0.5 mils) can be achieved. Although heat exchange assemblies have relatively complex shapes, the coating is uniform over the entire area coated at all angles and positions from the vertical and so tightly adherent and tenacious that the bond cannot be disrupted without destroying the graphite interface. The fluoropolymer enters the pores and crevices of the graphite and reacts in situ to seal the graphite. Consequently, problematic microporosity is minimized.

Sections of the graphite which are not coated with the fluoropolymer may be impregnated with a phenolic based resin or another material. The fluoropolymer coating helps to seal the graphite-to-silicon carbide tube intersection and prevent leakage. The service side, because it is typically free of coating, is made impervious by impregnation.

The specific combination of three materials (graphite, alpha silicon carbide, and a fluoroelastomer polymer coating) of the present invention offers heat transfer assemblies increased corrosion resistance and permits higher design pressures. Each of the three materials of construction is inert and corrosion resistant. The invention may be applied equally well to all three types of conventional heat exchange assemblies: cylindrical block, rectangular or cubic block, and shell-and-tube assemblies.

Referring now to the drawing, wherein like reference numerals refer to like elements throughout, there are illustrated three exemplary types of heat exchange assemblies incorporating the subject invention. The application of the three materials of construction of the subject invention to the cylindrical block heat exchange assembly is discussed in most detail for purposes of illustration.

I. Cylindrical Block Heat Exchange Assembly

Turning first to the cylindrical block type of heat exchange assembly, FIGS. 1A, 1B, and 1C show top, bottom, and side views, respectively, of a conventional cylindrical block heat exchange assembly 10. Cylindrical block heat exchange assembly 10 is the most versatile of the various designs because it is best suited for a wide variety of applications. Cylindrical block heat exchange assembly 10 has a top compression plate 12 and a bottom compression plate 14. Compression plates 12 and 14 may be made of steel or other suitable material.

Mounting lugs 16 are provided (preferably 180 degrees radially opposite each other) to position cylindrical block heat exchange assembly 10 in an appropriate location for removing or applying heat from or to a process fluid. Lifting lugs 18 are provided, preferably 180 degrees radially opposite each other, to facilitate transport and installation of cylindrical block heat exchange assembly 10. Cylindrical block heat exchange assembly 10 can be installed vertically or horizontally, in series, parallel or in combinations to any suitable framework or floor structure. A nameplate bracket 22 may be provided for identification purposes.

Turning specifically to FIG. 1C, multiple monolithic intermediate blocks 20, formed of fine grain graphite suitable as a substrate for a fluoropolymer coating, are placed between top compression plate 12 and bottom compression plate 14. The number of intermediate blocks 20 may be varied depending upon the application; twelve is a typical number. Surrounding intermediate blocks 20 is a shell 24. Shell 24 has a top flange 26 and a bottom flange 28. Shell 24 is preferably carbon steel but can also be lined, clad, or alloyed.

Intermediate blocks 20 are sealingly connected together, as shown in FIG. 1C, using block gaskets 30 to form a columnar assembly. Block gaskets 30 may be formed of Teflon® braid, neoprene rubber, or the like. Similarly, intermediate blocks 20 engage shell 24 using shell baffles 32. Neoprene rubber is a suitable material for shell baffles 32. Block gaskets 30 and shell baffles 32 may be combined to form a block gasket and shell baffle unit 34 (see FIG. 1D). An axial baffle bar 35 may also be provided and may be constructed of a metal such as stainless steel. Block gaskets 30 and shell baffles 32 prevent intermediate blocks 20 from becoming cemented either together or to shell 24 and assure that cylindrical block heat exchange assembly 10 is leak tight.

Although multiple intermediate blocks 20, as shown in FIG. 1C, may be used to form the columnar graphite block used in cylindrical block heat exchange assembly 10, a single, monolithic block would also suffice. Multiple intermediate blocks 20 are often preferable to a single, monolithic block because manufacture is made easier. In addition, the heat exchange surface of cylindrical block heat exchange assembly 10 can be increased by adding more intermediate blocks 20; this can be done at the site of use. Maintenance costs are low because cleaning and servicing are simplified by the ease of dismantling (and replacing, if necessary) intermediate blocks 20 on site. Similarly, although the shape of cylindrical block heat exchange assembly 10 may be cylindrical, as shown in FIG. 1C, other shapes would be suitable.

A floating joint 36 is placed between top compression plate 12 and top flange 26 of shell 24. A plurality (typically twelve) of floating end bolts 38, each with a spring 40 and a pair of nuts 42, are provided to connect top compression plate 12 to top flange 26 of shell 24-- holding floating joint 36 therebetween. Springs 40 may be steel coil springs. Floating flange bolting 46 is provided to connect floating header 44 to top compression

plate 12 through top header flange 48. Because graphite is inherently weak in tension and strong in compression, cylindrical block heat exchange assembly 10, with its axial spring compression principle, accommodates higher design pressures. There are no cemented joints to be attacked by process fluids.

A fixed joint 52 is created between bottom compression plate 14 and bottom flange 28 of shell 24. A plurality (typically twelve) of fixed end bolts 54, each with a nut 56, are provided to connect bottom compression plate 14 to bottom flange 28 of shell 24. Fixed flange bolting 58 is provided to connect fixed header 60 to bottom compression plate 14 through bottom header flange 62.

Projecting radially from shell 24 are a service inlet 68 and a service outlet 70. Service inlet 68 and service outlet 70 are preferably made of graphite. A multiplicity of service passageways 74 are machined radially through each intermediate block 20 of graphite. Intermediate blocks 20 can be impregnated with advanced polymers (such as TFE) to resist most corrosives and solvents, up to about 450°F, with the exception of certain concentrated, strong oxidizers such as HNO_3. The number and diameter of service passageways 74 provided depends upon the application. For purposes of example only, one hundred and forty-four service passageways 74 of approximately 3/8-inch diameter are suitable for some applications.

Service passageways 74 define a travel path 76 (illustrated by the arrows 76 in FIGS. 1C and 1D) for the service (cooling or heating) fluid used in cylindrical block heat exchange assembly 10. Water and steam are common service fluids. The service fluid enters cylindrical block heat exchange assembly 10 at service inlet 68 (shown by arrows A in FIGS. 1C and 1D), follows travel path 76, and exits cylindrical block heat exchange assembly 10 at service outlet 70 (shown by arrows B in FIGS. 1C and 1D).

Floating header 44 defines a process outlet 64 and fixed header 60 defines a process inlet 66. Process outlet 64 and process inlet 66 are preferably made of graphite. A multiplicity of process bores 72, machined axially through each intermediate block 20 of graphite, connect process inlet 66 and process outlet 64. The number and diameter of process bores 72 provided depends upon the application. For purposes of example only, ninety-eight process bores 72 of approximately 5/8-inch diameter are illustrated in FIG. 1E (an alternative example would be fifty-seven process bores 72 of approximately 3/4-inch diameter). The process fluid to be heated or cooled by cylindrical block heat exchange assembly 10 is delivered to process inlet 66 (shown by arrows C in FIGS. 1C and 1D), travels through process bores 72, and exits cylindrical block heat exchange assembly 10 at process outlet 64 (shown by arrows D in FIGS. 1C and 1D).

Examples of the many different process fluids which cylindrical block heat exchange assembly 10 accommodates are battery acids (H_2SO_4) and acetones. Multiple passes can be arranged, for both the process and service fluids, as desired.

Axial process bores 72 are independent of, and are carefully sealed away from, radial service passageways 74. There is no intersection between process bores 72 and service passageways 74. Process bores 72 and service passageways 74 do lie in extremely close proximity to each other, however, and form an interlocking grid throughout cylindrical block heat exchange assembly 10. The geometric relationship between process bores 72 and service passageways 74 facilitates efficient heat transfer or exchange between the process fluid traveling in process bores 72 and the service fluid traveling in service passageways 74.

FIG. 1E further illustrates the geometric relationship between process bores 72 and service passageways 74. FIG. 1E is an enlarged sectional view taken along the line 1E-1E of FIG. 1C. The alternating rows of process bores 72 and service passageways 74 assure maximum heat transfer. Although it can be exceeded for certain applications with water-cooled heads, the typical design temperature for conventional cylindrical block heat exchange assembly 10 is about 360°F. The maximum allowable working pressure is typically about 100 psig.

FIGS. 2A and 2B illustrate intermediate block 20 of conventional cylindrical block heat exchange assembly 10 (as discussed in detail above) in accordance with the present invention. First, silicon carbide tubes 80 are inserted into process bores 72 after the bores are drilled in graphite intermediate blocks 20. Tubes 80 are "forced" into process bores 72, because the outside diameter of tubes 80 are equal to or slightly less than the outside diameter of process bores 72, to assure a tight fit and maximum heat exchange. Tubes 80 may have a wall thickness of about 1/16 inches. Heat transfer occurs across the silicon carbide and then through the graphite. Silicon carbide tubes 80 offer increased corrosion resistance over bare graphite process bores 72.

Although tubes 80 could also be inserted into service passageways 74, little advantage would be gained unless the service fluid were corrosive. Moreover, service passageways 74 may be uncoated, or may be coated with resin or other similar material having a much lower temperature capability than silicon carbide tubes. Service passageways 74 may be uncoated or coated only with resin because temperatures are sufficiently low in these passageways so that protection of the graphite intermediate blocks 20 is unnecessary or decomposition of the resin does not occur.

Tubes 80 may be bonded in process bores 72 by an adhesive. A suitable adhesive is Cotronics Corporation's ceramic cement 901(-2), Sermabond 487, or the like. As shown in FIG. 2B, tubes 80 may project outside process bores 72 by a nominal amount (e.g., 0.25 inches). Tubes 80 can also be made flush with the face of graphite intermediate block 20 or recessed slightly within process bores 72. A frictional locking of tubes 80

in process bores 72 can be accomplished using graphite dust particles, dust also serving to maximize heat transfer.

A fluoropolymer coating 90 is deposited on certain external surfaces of cylindrical block heat exchange assembly 10 and on the ends 82 of silicon carbide tubes 80. Typically, fluoropolymer coating 90 need be applied only to the faces 20a, 20b of intermediate block 20 from which process bores 72 exit. This is especially true when the service fluid is water. Alternatively, fluoropolymer coating 90 may also be applied to the faces 20c, 20d of intermediate block 20 from which service passageways 74 exit. As illustrated in FIG. 2B, a recess 92 may be provided in intermediate block 20 to allow dimensionally for the extension of tubes 80 and for fluoropolymer coating 90.

II. Cubic Block Heat Exchange Assembly

Illustrated in FIGS. 3A, 3B, and 3C is a conventional, cubic block heat exchange assembly 110. Cubic heat exchange assembly 110 has, as its central component, a cubic block 112. Cubic block 112 is made of graphite and forms the core of cubic heat exchange assembly 110 The graphite of cubic block 112 may be impregnated with a polymer such as PTFE.

Like cylindrical heat exchange assembly 10, cubic block 112 of cubic heat exchange assembly 110 has alternating rows of process bores 172 and service passageways 174 to assure maximum heat transfer. Process bores 172 are independent of, and are carefully sealed away from, service passageways 174. There is no intersection between process bores 172 and service passageways 174. Process bores 172 and service passageways 174 do lie in extremely close proximity to each other, however, and form an interlocking grid throughout cubic heat exchange assembly 110.

The geometric relationship between process bores 172 and service passageways 174 facilitates efficient heat transfer or exchange between the process fluid traveling in process bores 172 and the service fluid traveling in service passageways 174. Typically, process bores are either 3/8-inch diameter or 5/32-inch diameter. The smaller diameter option is generally used for condensation applications but is also suitable for clean liquids. Although not standard, graphite tubes having a 3/4-inch or 1/2-inch diameter can be placed in process bores 172 to meet special requirements.

The right angle relationship between process bores 172 and service passageways 174 provides a constant counter current flow; this eliminates temperature correction factors in multipass cubic heat exchange assembly 110. Heat transfer areas are thereby greatly reduced.

A clamping plate casting 114 provides structural support for cubic block 112. Clamping bolts 116 extending from clamping plate casting 114 engage the remaining components of cubic heat exchange assembly 110 and affix those components in relation to cubic block, 112.

A process head liner 118 and a process return liner 120 are positioned over the two, opposing faces of cubic block 112 from which process bores 172 exit. Process head liner 118 and process return liner 120 are each preferably made of graphite, coated in raw state with fluoropolymer, impregnated after coating, and mounted in metal. A process head casting 122, having a process inlet 166 and a process outlet 164, seats on clamping bolts 116 and covers process head liner 118. A process return head casting 124 similarly seats on clamping bolts 116 and covers process return liner 120. Process head casting 122 and process return head casting 124 are preferably made of steel.

Although liners might be used on the service side of cubic block 112, they are not usually necessary (and are not shown in FIG. 3A). Positioned over the two, opposing faces of cubic block 112 from which service passageways 174 exit are a service head 126, having a service inlet 168 and a service outlet 170, and a service return head 128. Service head 126 and service return head 128 seat on clamping bolts 116 and are preferably made of steel.

Cubic heat exchange assembly 110 is one of the most maintenance-free types of heat exchange assemblies ever designed; all graphite is kept in compression. Cubic heat exchange assembly 110 will take overloads, including thermal, hydraulic, and external mechanical shock, without failure. Simplicity of design, ease of disassembly for mechanical cleaning, and a large number of sizes and pass arrangements all contribute to the versatility of cubic heat exchange assembly 110.

Conventional cubic heat exchange assembly 110 is manufactured in size ranges having heat transfer areas from 10 ft^2 to 1,000 ft^2. Passes are available from a single pass to sixty passes depending upon the model. Shown in FIG. 3B is a three-pass configuration; FIG. 3C illustrates a four-pass configuration. The flow paths of the process fluid are indicated by arrows.

Selection of the correct pass arrangement, in order to provide the minimum heat transfer resistance, is of primary importance. The higher the velocity, the less the resistance, especially in the turbulent range. Care must be taken, however, to avoid excessive pressure drop. In most cases, for a liquid specific gravity of 1, a velocity of 3-4 ft/sec can be used for good efficiency.

TFE process gaskets (not shown) are standard components. There are no internal gaskets in cubic heat exchange assembly 110. The physical size of cubic heat exchange assembly 110 will often be one-fifth the volume of the comparable shell-and-tube type graphite heat exchange assembly discussed below. Cubic heat exchange assembly 110 is especially advantageous, therefore, for applications where space constraints exist.

FIGS. 4A and 4B illustrate cubic block 112 of conventional cubic heat exchange assembly 110 (as discussed in detail above) in accordance with the present invention. For purposes of example only, cubic block 112 may be 8.75 inches high, have a 9.5-inch depth and

a 9.5-inch width, and be drilled with 1/2-inch diameter process bores 172 and 3/8-inch diameter service passageways 174. Silicon carbide tubes 180 are inserted into process bores 172. Tubes 180 are "forced" into process bores 172, because the outside diameter of tubes 180 almost equals the outside diameter of process bores 172 (about 1/2-inch), to assure a tight fit and maximum heat exchange. Although tubes 180 could also be inserted into service passageways 174, little advantage would be gained unless the service fluid were corrosive.

Tubes 180 may be bonded in process bores 172 by an adhesive, or frictionally locked using graphite powder. As shown in FIG. 4B, tubes 180 are flush with the face of graphite cubic block 112. Alternatively, tubes 180 may project outside process bores 172 by a nominal amount (e.g., 0.25 inches) or be recessed slightly within process bores 172.

A fluoropolymer coating 190 is deposited on certain external surfaces of cubic heat exchange assembly 110 and on the ends 182 of silicon carbide tubes 180. (Fluoropolymer coating 190 is shown in partial cut-away in FIG. 4A.) Typically, fluoropolymer coating 190 need be applied only to the faces of cubic block 112 from which process bores 172 exit. This is especially true when the service fluid is water. Alternatively, fluoropolymer coating 190 may also be applied to the faces of cubic block 112 from which service passageways 174 exit. Even when the four faces of cubic block 112 receive fluoropolymer coating 190, the top and bottom of cubic block 112 need not be coated.

The amount of fluoropolymer coating 190 applied to the faces of cubic block 112 depends on the application. Twenty-five mils of fluoropolymer coating 190 are suitable in some applications, for example, while 8-10 mils may suffice in other applications. Although ends 182 of tubes 180 are coated, no coating is applied to the inside diameters of tubes 180. A slightly deeper gasket groove may be provided in the liners 118, 120 to allow dimensionally for the extension of tubes 180 (if they extend) and for fluoropolymer coating 190.

III. Shell-and-Tube Heat Exchange Assembly

The concept of the present invention may be used in heat exchange assemblies of any desired shape (as discussed above), and is also adaptable to tubular heat exchange assemblies. As is known in the art, the use of heat exchange assemblies of a tubular configuration is highly advantageous in certain environments in which it is desired that the heat exchange take place entirely within the exchange assembly. The tubular heat exchange assembly commonly in use in such an environment is of the type known in the art as "shell-and-tube" heat exchange assemblies. A plurality of tubular elements conveying one heat exchange medium are arranged within a shell through which is circulating another heat exchange medium with or without the use of baffles to direct the flow. The flow is substantially axial along the tubes.

A conventional shell-and-tube heat exchange assembly 210 is illustrated in FIG. 5. The process fluid is introduced into shell-and-tube heat exchange assembly 210 through process inlet 266, flows through the tubes 212 disposed within the outer shell 214, and exits from process outlet 264. Tubes 212 are typically metal, alpha silicon carbide, glass, or impervious graphite. Shell 214 is, for example, low temperature steel, stainless steel, or fiberglass. The service fluid enters shell-and-tube heat exchange assembly 210 through service inlet 268, flows around tubes 212 as directed by service baffles 216, and exits from service outlet 270. In essence, the service fluid traverses shell-and-tube heat exchange assembly 210 through "passageways" defined by service baffles 216 and tubes 212. Service baffles 216 are typically stainless steel, fiberglass, or polypropylene.

Tubes 212 are held within shell 214 by tube sheets. The ends of tubes 212 nearest process inlet 266 are held in first tube sheet 218; the ends of tubes 212 nearest process outlet 264 are held in second tube sheet 220. Tube sheets 218, 220 are typically metal, impervious graphite, or glass-filled PTFE. Bores are drilled in tube sheets 218, 220 to accommodate tubes 212. Packing 222 may be provided between tube sheet 220 and shell 214 to secure tube sheet 220 in position. Internal process gaskets 224 are provided to seal tube sheets 218, 220.

First process head 226 and second process head 228 engage first tube sheet 218 and second tube sheet 220, respectively, to hold tube sheets 218, 220 in position. First process head 226 and first tube sheet 218 are located in the fixed end 230 of shell-and-tube heat exchange assembly 210. Second process head 228 and second tube sheet 220 are located in the floating end 232 of shell-and-tube heat exchange assembly 210. Tie rods 234 and split ring flanges 236 are provided on floating end 232 to apply compression to shell-and-tube heat exchange assembly 210. Tie rods 234 are typically stainless steel, fiberglass, or polypropylene.

An improved shell-and-tube heat exchange assembly in accordance with the present invention is shown in FIG. 6. Tube sheets 218, 220 are graphite and tubes 280 are alpha silicon carbide. A fluoropolymer coating 290 is applied on the face of tube sheets 218, 220 nearest process heads 226, 228, respectively. The joint between silicon carbide tubes 280 and graphite tube sheets 218, 220 is sealed by fluoropolymer coating 290. The graphite may be impregnated (e.g., with a phenolic) on the remaining faces of tube sheets 218, 220. Fluoropolymer coating 290 is also applied to the ends 282 of tubes 280. Fluoropolymer coating 290 is not applied, however, inside tubes 280. Process heads 226, 228 are graphite coated with fluoropolymer and encased in steel.

As improved with silicon carbide tubes 280 and fluoropolymer coating 290 of the present invention, tube bundle heat exchange assembly (218, 220, 280) is a single piece construction. Thus, the entire bundle (218, 220, 280) is coated with tube sheets 218, 220 and tubes 280 fully assembled. Subsequently, tube sheets 218, 220 are impregnated. There are no internal gaskets which service fluids can migrate around. The tube side-construction offers materials of construction (silicon carbide and fluoropolymer-coated graphite) which resist contamination.

IV. Examples

A. Coating evaluation tests have been conducted. Two different fluoropolymer materials, a copolymer of ethylene and chlorotrifluoroethylene (ECTFE) (sold under the trademark Halar by Ausimont U.S.A., Inc.) and a copolymer of ethylene and trifluoroethylene .(ETFE) (sold under the trademark Tefzel by E.I. du Pont de Nemours Company), were applied to un-impregnated graphite heat exchange liners. In each case, a neoprene gasket was cut to fit the liner and a first steel plate with its own gasket was placed over the liner. Finally, a second steel plate was placed over the first steel plate.

The test pieces were placed in a test stand and a load pressure applied up to 550 psi. Air pressure was added in three stages of 15 psig (for 5 minutes), 20 psig (for 5 minutes), and 30 psig (for 30 minutes) and the test piece checked for air leakage at each stage using a soap-water solution. No leaks were observed.

A temperature cycle was also applied to the test pieces to determine the flexibility of the coating in extreme heat conditions. The pieces were placed in a gas-fired oven and heated to 350°F for two hours. During the test, the pieces were checked every 15 minutes for softness and peeling. The coatings held up well.

After the air test and temperature tests were completed, the graphite lines of the test pieces were impregnated with a phenol-formaldehyde resin. A two-day cycle showed the coated liners an extensive vacuum along with higher pressure and temperature changes. Upon completion of the test cycle, the two test pieces were placed under an ambient vacuum for 1-2 hours. Again, the coatings held up well.

B. Corrosion tests were conducted on fluoropolymer coated graphite samples. Two graphite samples were coated with fluoropolymer (ECTFE) by electrostatic spray. The thickness of the coating was 0.8 mm. Both samples were tested in concentrated hydrochloric acid at a temperature of 110°C for a duration of 1000 hours. A microscopic examination revealed a good bond between the graphite and fluoropolymer and the absence of chemical attack by the acid. The coating held tight to the graphite. FEP was also tested under similar conditions with the same result.

C. Heat transfer tests were conducted on a cubic block heat exchange assembly with silicon carbide tubes inserted in both the process bores and service passageways. The heat transfer area (H.T.A.) for both the process and service sides was 12.3 ft^2. The cubic block was formed of Grade 2020 graphite without phenolic impregnation. The design was a 10 X 10 pass assembly, with 156 silicon carbide tubes, each having a 1/2-inch outside diameter, a 3/8-inch inside diameter, and an effective length of 9 1/2 inches. An FEP coating was applied on all four faces of the cubic block.

Water at 1800 lbs./hr. and 50°F was heated to 175°F using saturated steam at 1 atm and 212°F. The water heat up rate was 225,000 Btu/hr. and the steam flow rate was about 230 lbs./hr. In summary, the film coefficient data was: h_S(water) = 299 Btu/Hr.-ft^2-°F, hp(steam) = 2500 Btu/Hr.-ft^2-°F. The Log Mean Temperature Difference (LMTD) was 81.5 °F. Assuming that the assembly was free of fouling and used all of the available area, then $U_C = U_D = U_S$ = 224 Btu/Hr.-ft^2-°F (where U_C is the coefficient for a "clean" assembly, U_D is the coefficient for a "dirty" assembly, and U_S is the coefficient for the assembly in actual service).

These results lead to a wall resistance of 1390 Btu/Hr.-ft^2-°F or 0.00072 °F-Hr.-ft^2/Btu. This is about two times higher than for a conventional cylindrical heat exchange assembly impregnated with stabilized Bakelite (Bakelite is a trademark registered by Union Carbide Corporation). These numbers are for a wall resistance of two silicon carbide tubes and 0.15-inch un-impregnated graphite.

Although illustrated and described herein with reference to certain specific embodiments, the present invention is nevertheless not intended to be limited to the details shown. Rather, various modifications may be made in the details within the scope and range of equivalents of the claims and without departing from the spirit of the invention.

Claims

1. A heat exchange assembly for efficient heat transfer between a process fluid and a service fluid comprising:

    a thermally conductive graphite body having:

        (a) an external surface,

        (b) a plurality of bores receiving the process fluid, and

(c) a plurality of passageways receiving the service fluid, said bores and said passageways facilitating efficient heat transfer between the process fluid and the service fluid;

a multiplicity of silicon carbide tubes having ends and an internal diameter and being disposed in at least one of (i) said plurality of bores and (ii) said plurality of passageways; and

a fluoropolymer coating disposed on said external surface of said graphite body and on said ends of said silicon carbide tubes, said internal diameter of said silicon carbide tubes being devoid of said coating.

2. The heat exchange assembly according to claim 1 wherein said tubes are alpha silicon carbide.

3. The heat exchange assembly according to claim 1 wherein said tubes have a wall thickness of about 1/16 inches.

4. The heat exchange assembly according to claim 1 wherein said tubes have an outside diameter, said bores have a diameter, and said outside diameter of said tubes is approximately equal to said diameter of said bores.

5. The heat exchange assembly according to claim 4 wherein said tubes are bonded in said bores by at least one of an adhesive, a frictional lock using graphite dust, and impregnation using a resin.

6. The heat exchange assembly according to claim 4 wherein said ends of said tubes project outside said bores.

7. The heat exchange assembly according to claim 4 wherein said ends of said tubes are flush with said graphite body.

8. The heat exchange assembly according to claim 4 wherein said ends of said tubes are recessed in said bores.

9. The heat exchange assembly according to claim 1 wherein said fluoropolymer coating is a fluoroelastomer polymer.

10. The heat exchange assembly according to claim 9 wherein said fluoroelastomer polymer coating is selected from the group consisting of polytetrafluoroethylene and a copolymer of tetrafluoroethylene and hexafluoropropylene.

11. The heat exchange assembly according to claim 9 wherein said fluoroelastomer polymer coating is a continuous, adherent, homogeneous, coating of substantially uniform thickness.

12. The heat exchange assembly according to claim 1 wherein said graphite body is un-impregnated.

13. The heat exchange assembly according to claim 1 wherein said external surface of said graphite body has first areas upon which said fluoropolymer coating is disposed and second areas devoid of said fluoropolymer coating, said second areas being impregnated.

14. The heat exchange assembly according to claim 13 wherein said second areas of said external surface of said graphite body are impregnated with one of tetrafluoroethylene and phenolic resin.

15. The heat exchange assembly according to claim 1 wherein said graphite body is impregnated with one of tetrafluoroethylene and phenolic resin.

16. The heat exchange assembly according to claim 1 wherein said silicon carbide tubes are disposed only in said plurality of bores and said plurality of passageways are uncoated.

17. The heat exchange assembly according to claim 1 wherein said silicon carbide tubes are disposed only in said plurality of bores and said plurality of passageways are coated with a resin.

18. The heat exchange assembly according to claim 1 wherein said graphite body is selected from the group consisting of at least one cylindrical block, at least one cubic block, and at least one tube sheet.

19. A cylindrical block heat exchange assembly for efficient heat transfer between a process fluid and a service fluid comprising:

a first compression plate;

a second compression plate;

at least one graphite intermediate block disposed between said first compression plate and said second compression plate and having:

(a) an external surface,

(b) a plurality of bores receiving the process fluid and exiting said external surface, and

(c) a plurality of passageways receiving the service fluid, said bores and said passageways forming an interlocking and non-intersecting grid throughout said intermediate block and facilitating efficient heat transfer between the process fluid and the service fluid;

a shell surrounding said intermediate block;

a multiplicity of silicon carbide tubes having ends and an internal diameter and being disposed in at least one of (i) said plurality of bores and (ii) said plurality of passageways; and

a fluoropolymer coating disposed on said external surface of said intermediate block and on said ends of said silicon carbide tubes, said internal diameter of said silicon carbide tubes being devoid of said coating.

20. The cylindrical block heat exchange assembly according to claim 19 having a single, monolithic, graphite intermediate block.

21. The cylindrical block heat exchange assembly according to claim 19 wherein said fluoropolymer coating is disposed only on those areas of said external surface of said intermediate block from which said bores exit.

22. A cubic block heat exchange assembly for efficient heat transfer between a process fluid and a service fluid comprising:

a graphite cubic block having:

(a) an external surface with four sides, two opposed process sides and two opposed service sides,

(b) a plurality of bores receiving the process fluid and exiting said process sides of said external surface, and

(c) a plurality of passageways receiving the service fluid and exiting said service sides of said external surface, said bores and said passageways forming an interlocking and non-intersecting grid throughout said cubic block and facilitating efficient heat transfer between the process fluid and the service fluid;

a clamping casting structurally supporting said cubic block;

clamping bolts extending from said clamping casting;

a process head liner and a process return liner respectively positioned over said two opposed process sides of said external surface of said cubic block;

a process head casting seated on said clamping bolts and covering said process head liner;

a process return head casting seated on said clamping bolts and covering said process return liner;

a multiplicity of silicon carbide tubes having ends and an internal diameter and being disposed in at least one of (i) said plurality of bores and (ii) said plurality of passageways; and

a fluoropolymer coating disposed on said two opposed process sides of said external surface of said cubic block and on said ends of said silicon carbide tubes, said internal diameter of said silicon carbide tubes being devoid of said coating.

23. The cubic block heat exchange assembly according to claim 22 wherein said process head liner and said process return liner are graphite, coated in raw state with fluoropolymer, impreghated after coating, and mounted in metal.

24. The cubic block heat exchange assembly according to claim 22 wherein said fluoropolymer coating is disposed on said two opposed service sides of said external surface of said cubic block.

25. A shell-and-tube heat exchange assembly for efficient heat transfer between a process fluid and a service fluid comprising:

an outer shell having a service inlet by which the service fluid enters said assembly, a service outlet by which the service fluid exits said assembly, a process inlet by which the process fluid enters said assembly, and a process outlet by which the process fluid exits said assembly;

a multiplicity of silicon carbide tubes having ends and an internal diameter and being disposed axially in said outer shell between said process inlet and said process outlet, said silicon carbide tubes carrying the process fluid from said process inlet to said process outlet;

at least one graphite tube sheet being disposed in said outer shell, having (a) an external sur-

face and (b) a plurality of bores holding said silicon carbide tubes, and defining (c) a plurality of passageways between said service inlet and said service outlet carrying the service fluid from said service inlet to said service outlet, said bores and said passageways facilitating efficient heat transfer between the process fluid and the service fluid;

a process head disposed in said outer shell and holding said tube sheet in position;

a fluoropolymer coating disposed on said external surface Of said tube sheet facing said process head and on said ends of said silicon carbide tubes, said internal diameter of said silicon carbide tubes being devoid of said coating.

26. The shell-and-tube heat exchange assembly according to claim 25 further comprising baffles disposed in said outer shell directing the service fluid in said passageways between said service inlet and said service outlet.

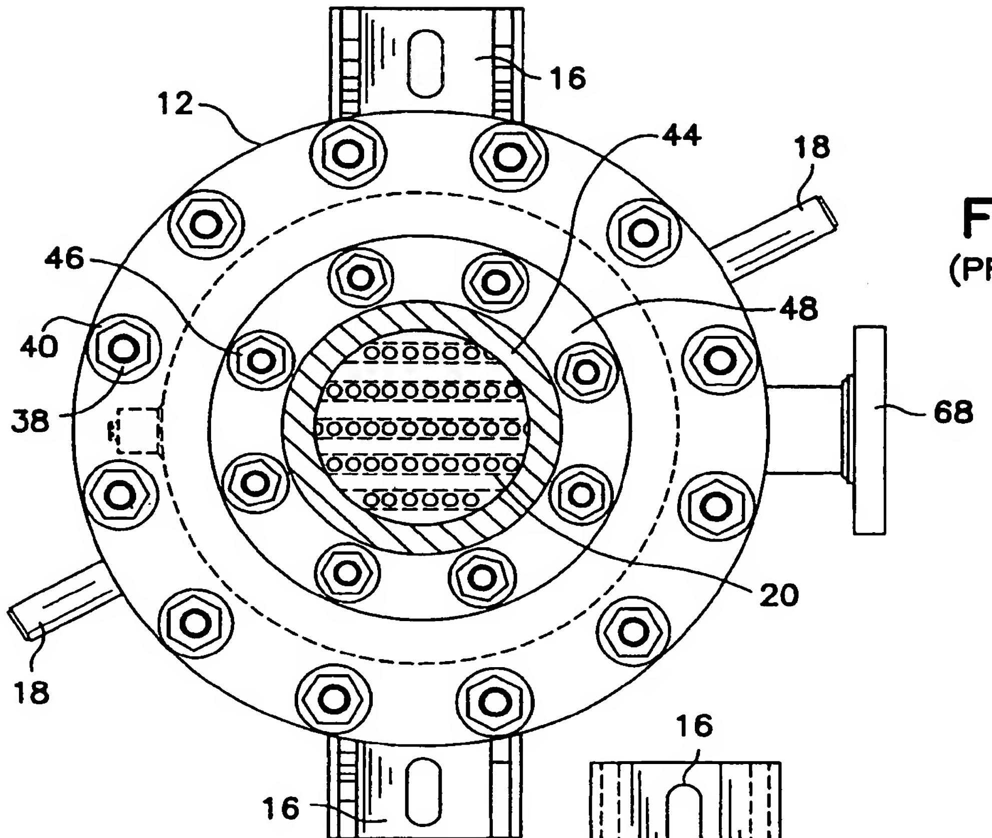

FIG. 1A
(PRIOR ART)

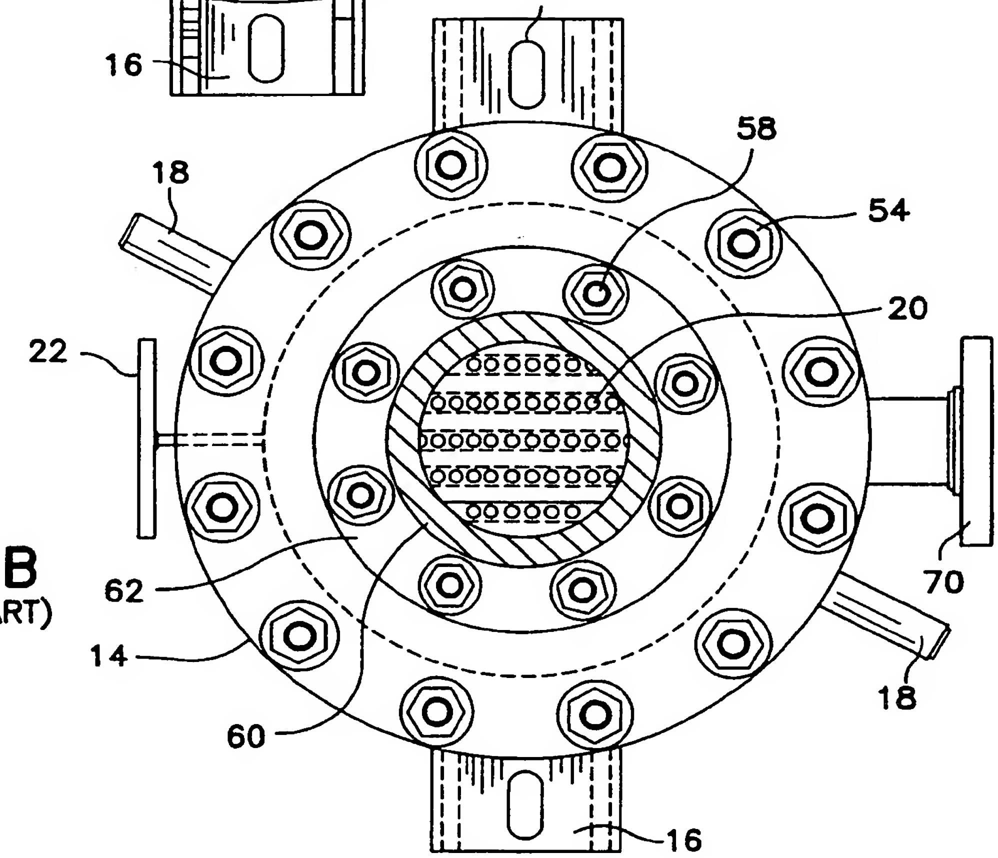

FIG. 1B
(PRIOR ART)

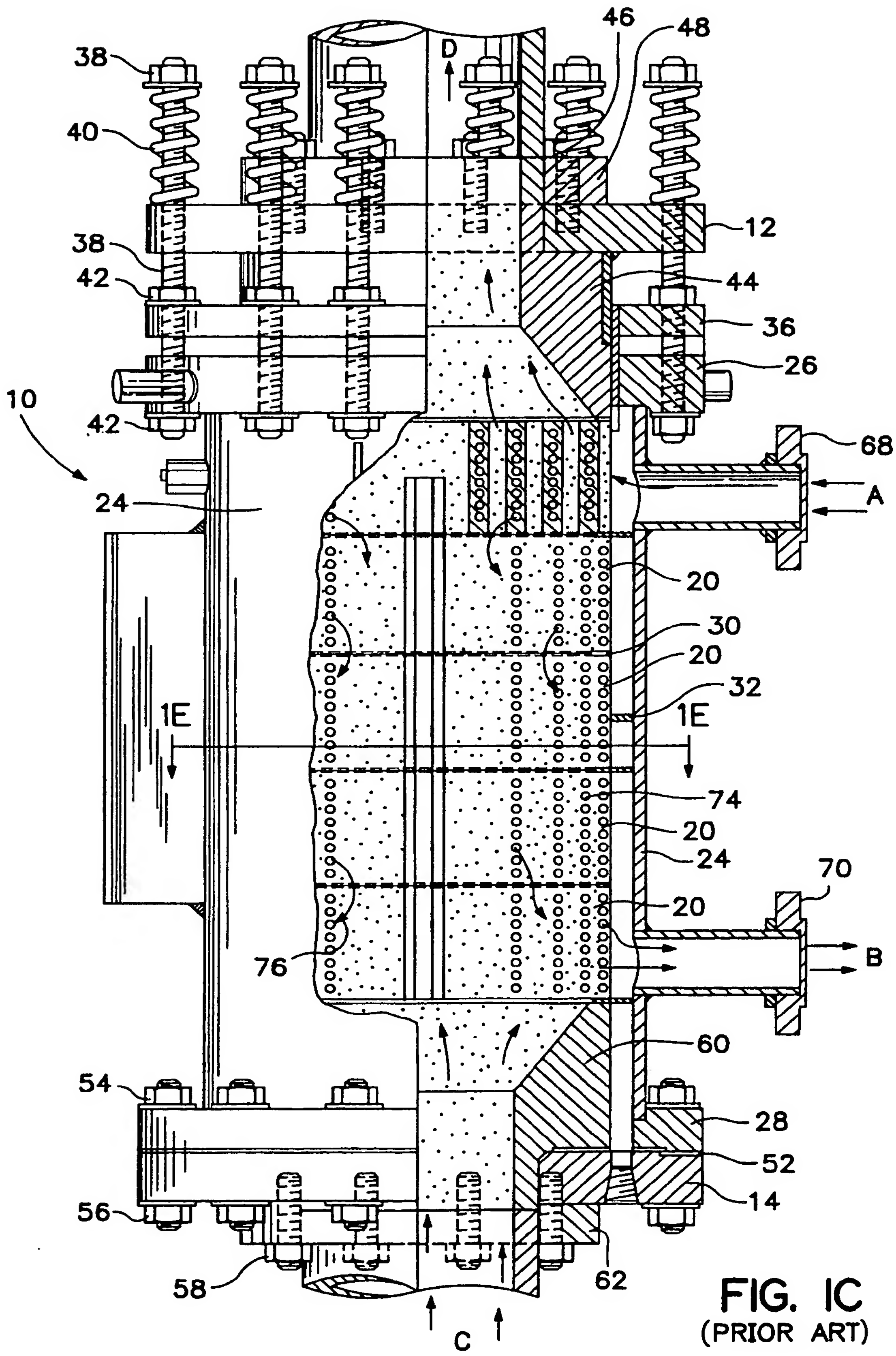

FIG. IC
(PRIOR ART)

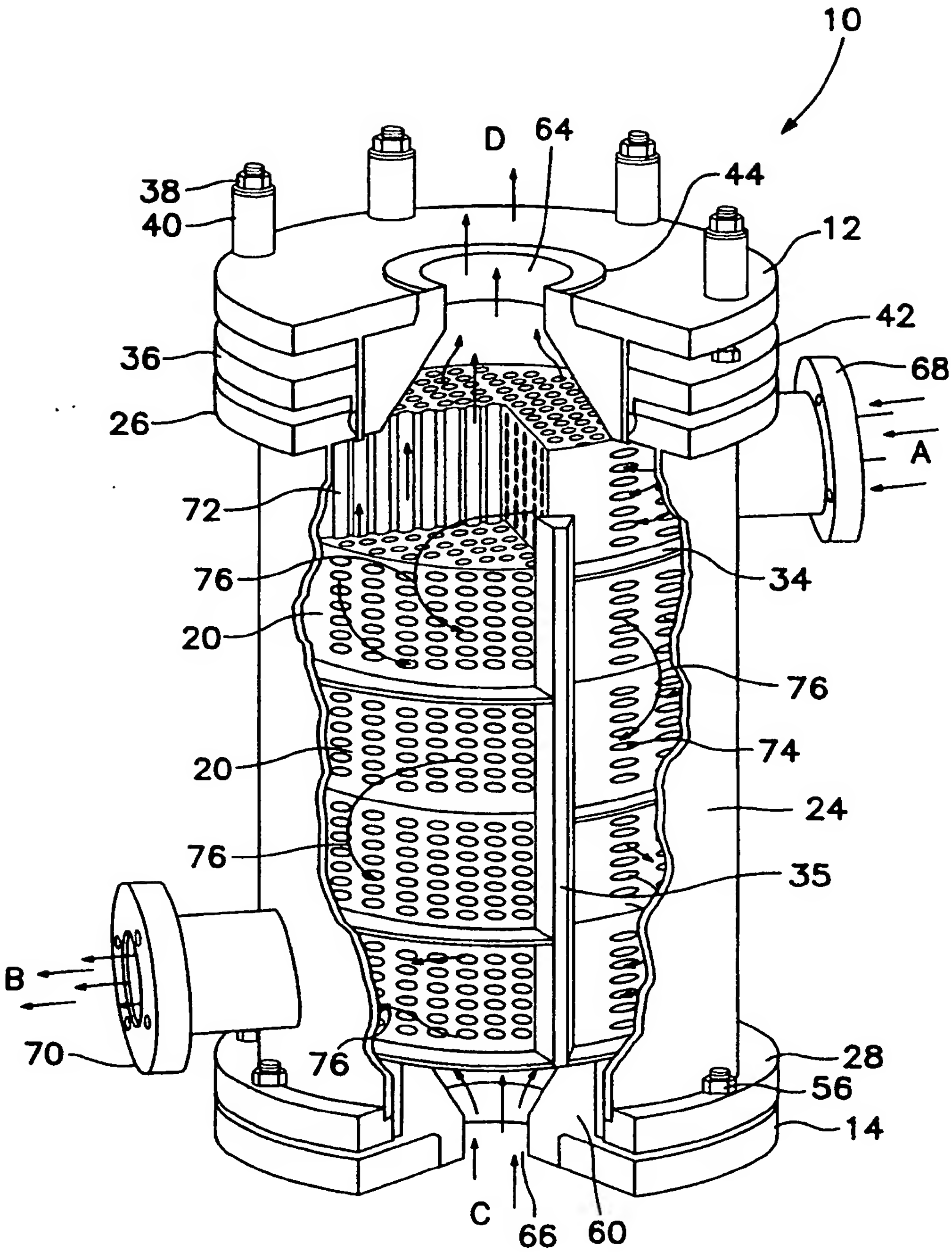

FIG. 1D
(PRIOR ART)

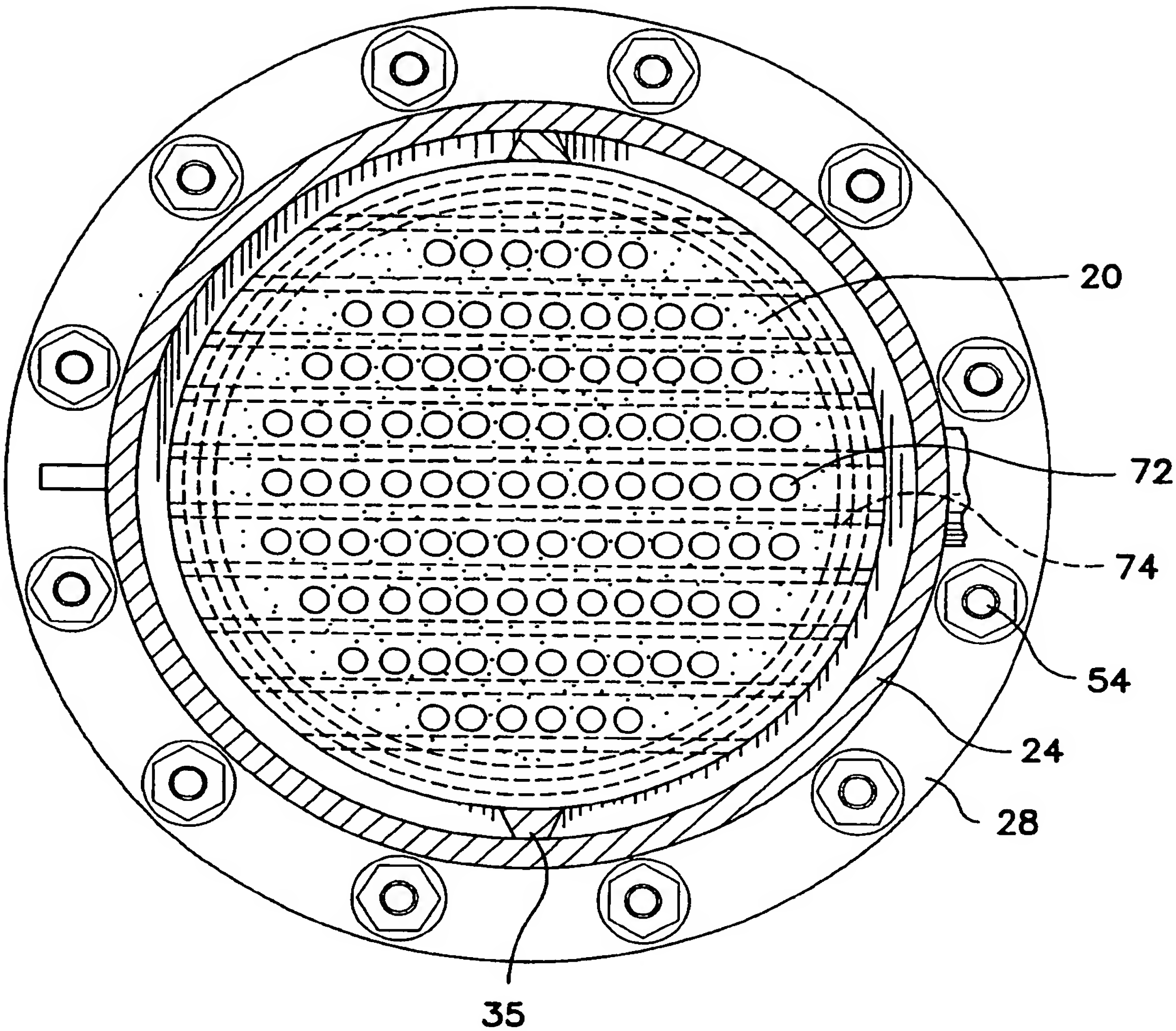

FIG. 1E
(PRIOR ART)

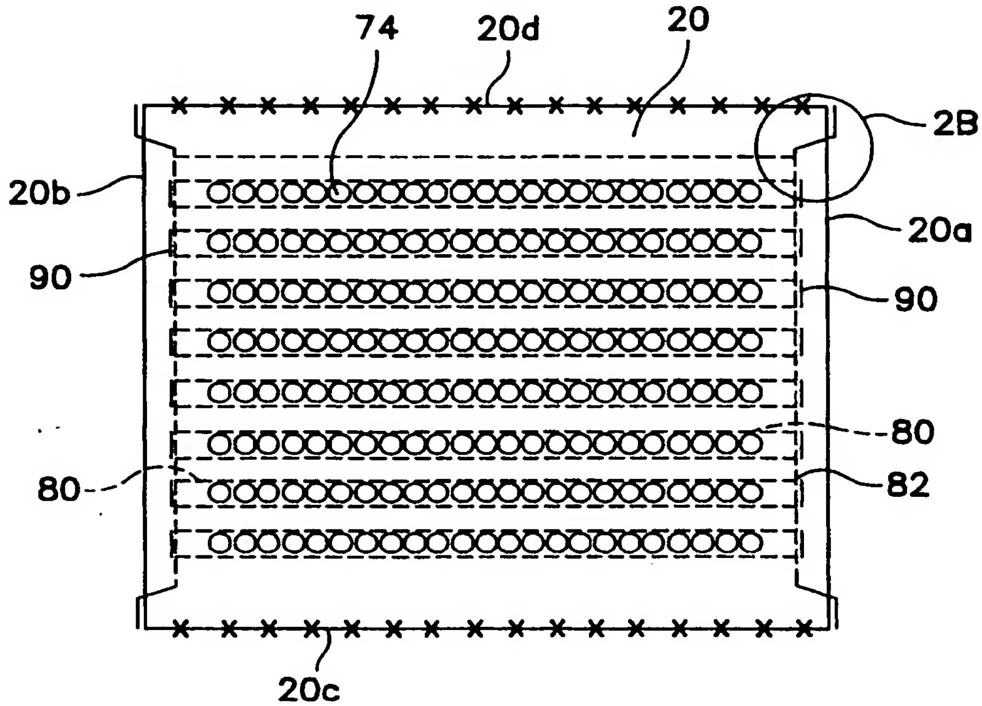

FIG. 2A

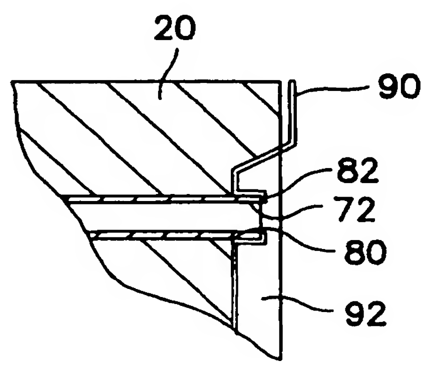

FIG. 2B

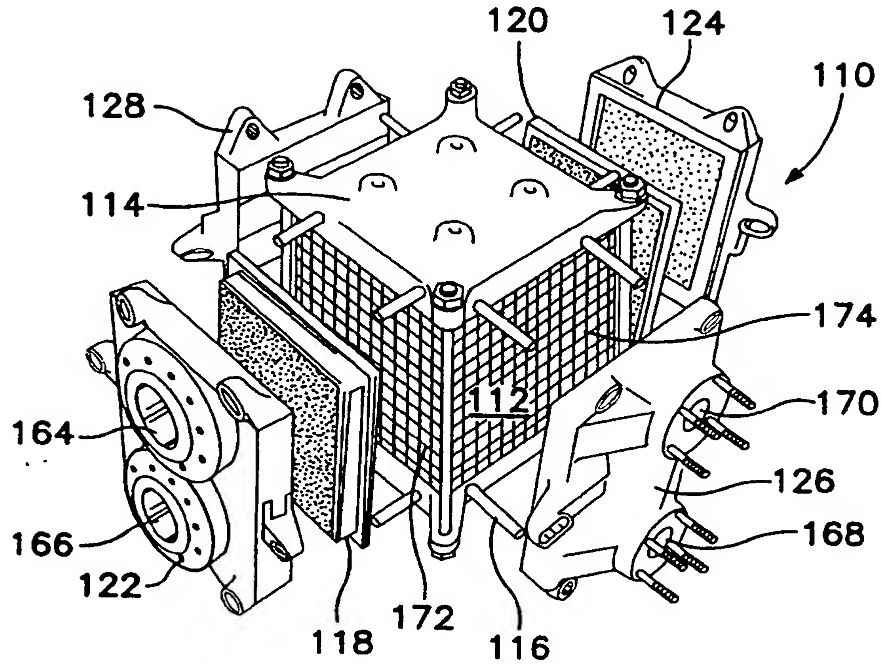

FIG. 3A
PRIOR ART

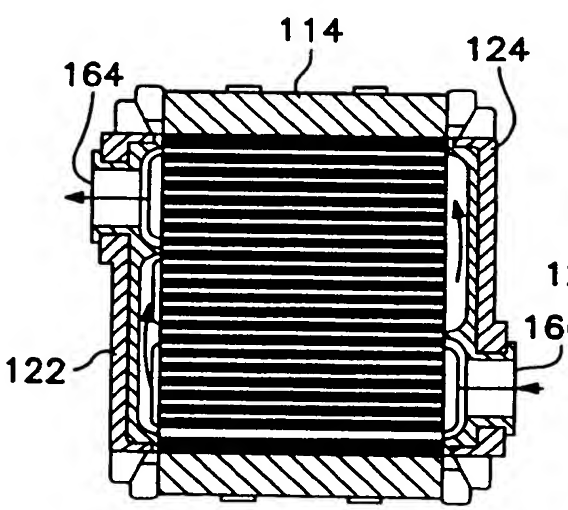

FIG. 3B
(PRIOR ART)

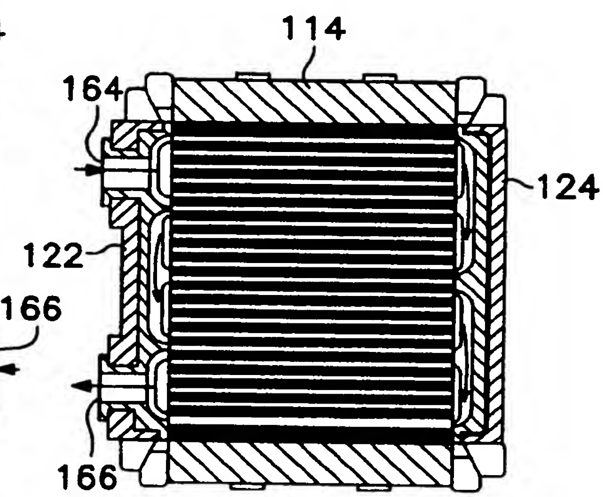

FIG. 3C
(PRIOR ART)

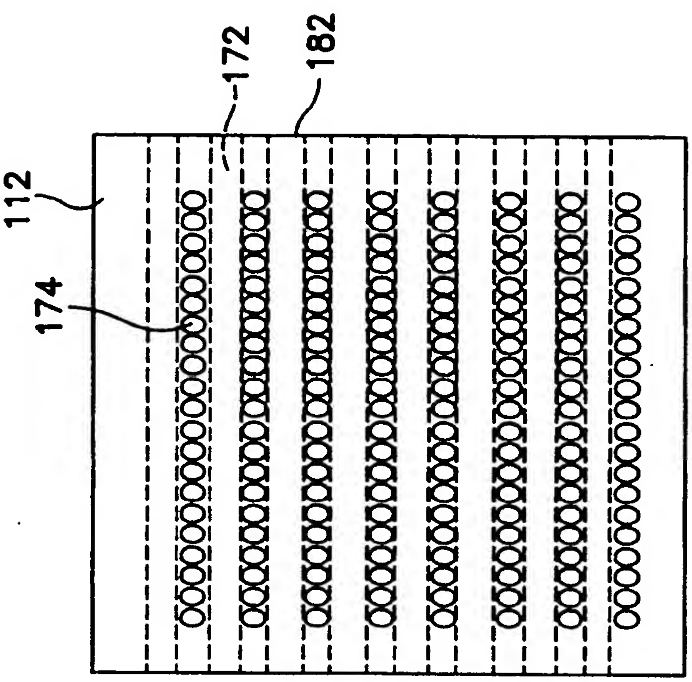

FIG. 4B

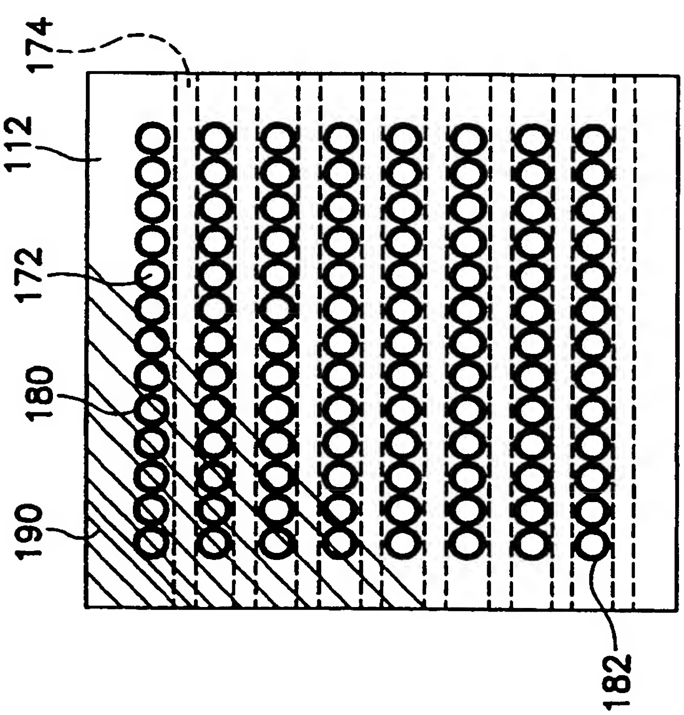

FIG. 4A

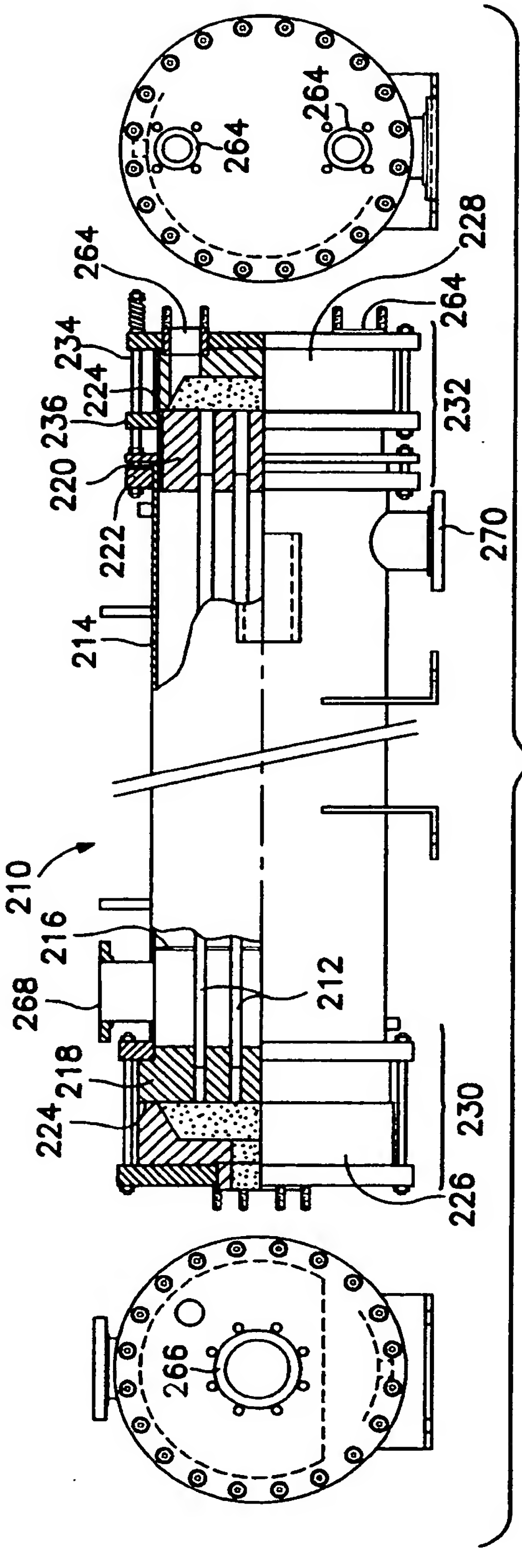

FIG. 5
(PRIOR ART)

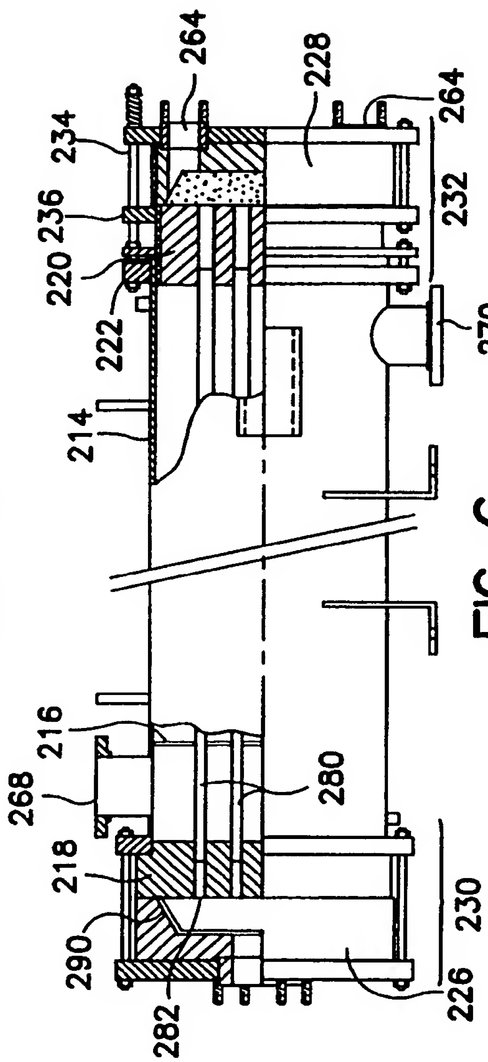

FIG. 6

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 96107387.1

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 6)
A	DE - A - 3 201 156 (CHEMADEX) * Fig. 1,3; abstract * --	1-26	F 28 F 21/02 F 28 F 19/04 F 28 D 7/00
A	DE - A - 2 220 670 (SIGRI) * Pages 4-5; fig. 1,2 * --	1-26	
A	DE - A - 3 117 187 (SIGRI) * Page 5, lines 18-32; fig. 2 * ----	1-26	

TECHNICAL FIELDS SEARCHED (Int. Cl.6)

F 28 F
F 28 D

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
VIENNA	02-09-1996	HUBER

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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